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6.14 INVESTIGATIONS OF THE LOWER AND MIDDLE ATMOSPHERE AT THE ARECIBO OBSERVATORY AND A DESCRIPTION OF THE NEW VHF RADAR PROJECT

J. Rottger*, H. M. Ierkic, R. K. Zimmerman, and J. Hagen

Arecibo Observatory
P.O. Box 995
Arecibo, Puerto Rico

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AY208300

INTRODUCTION

The atmospheric science research at the Arecibo Observatory, particularly the research of the lower and middle atmosphere, is performed by means of (active) radar methods and (passive) optical methods. The active methods utilize the 430-MHz radar (e.g., WOODMAN, 1980a; TSUDA et al., 1985), which is normally used for incoherent scatter investigations of the ionosphere (including the D region/mesosphere, e.g., MATHEWS, 1985), the S-band radar on 2380 MHz (e.g., WOODMAN, 1980b), which is normally used for investigations of planets and asteroids, the bistatic HF radar (GONZALES and WOODMAN, 1984), which is normally used as heating facility to modify the ionosphere, and a newly constructed VHF radar. The applications of the 430-MHz radar, the S-band radar and the HF radar were described by WOODMAN (1983). The VHF radar was particularly designed as an MST radar, although it also can be used for heating diagnostics. The VHF radar development was based on earlier experiences with a VHF radar system transported temporarily to the Observatory (e.g., ROTTGER et al., 1981), and will be described in more detail in this report.

The passive methods performed at the Observatory include measurements of the mesopause temperature by observing the rotational emissions from OH-bands (e.g., TEPLEY, 1985). The feasibility to use a lidar system to investigate the lower and middle atmosphere at the Arecibo Observatory is presently being studied. It would provide a valuable complement to the existing radars to measure temperature and trace constituent profiles.

Besides the present VHF radar, which is operated with the 1000-ft dish as antenna, an additional VHF system has been proposed. The proposal, submitted to the National Science Foundation, has been suspended, however. Such a stand-alone facility could operate continuously without interrupting other experiments carried out at the Observatory. The implementation of this system would be based on the presently existing radar transmitter and receiver. It could be set up in a valley close to the Observatory using a separate antenna system and should have an average power-aperture product of about 5.10^7 Wm^2, as well as a stand-alone radar control and data acquisition unit.

The scientific goals for such a system are presented elsewhere in this proceedings (ROTTGER et al., 1986). It is foreseen that continuous investigations of the neutral atmosphere in the tropical/subtropical zone of Puerto Rico will encompass such topics as: hurricanes and tropical storms, waves in the easterlies, quasi-inertial waves, tides and short-period gravity waves and their generation mechanisms such as shears in the subtropical jet stream and deep penetrative convection, momentum flux from the troposphere to the mesosphere due to gravity waves, kinetic energy spectra due to waves or turbulence, and land-sea breeze, lee waves and local convection. For the investigation of almost all of these processes, the island of Puerto Rico is a preferred site, and an ancillary VHF radar system should be built near the Arecibo Observatory to conduct such observations.

*On leave from Max-Planck-Institut fur Aeronomie, Katlenburg-Lindau, West Germany.

THE AO VHF RADAR

The new Arecibo Observatory VHF radar operates on 46.8 MHz with a 50 kW (peak) transmitter made by Tycho Technology Inc. The system uses the 1000-ft reflector with a newly designed feed antenna. The existing radar control and data-acquisition system is used in addition to additional control and monitor instrumentation which was particularly developed for the 46.8-MHz radar. The average power-aperture product is 4.10^7 Wm^2. The system is set up in two locally separated units: the radar control, signal detection, data-acquisition and monitor instruments are on the ground in the control room building. The transmitter and receiver frontends are located on the antenna platform 130 m above the dish in carriage house 1, to which the feed antenna is mounted. Whereas the carriage house part of the system is permanently configurated, experimenters have to set up for every experiment the different instruments needed in the control room.

ANTENNA

The 46.8-MHz feed presently is a twin 2-element antenna which is located on the downhill side of carriage house 1. Figure 1 shows the arrangement of the feed antenna on the platform. Its driven elements are 9.3 m below the paraxial surface and their center is at 5.3 m distance from the closely neighboring 430-MHz line feed. The clearance of 5.3 m was found to be sufficient for negligible coupling with the 46.8-MHz feed. The 46.8 MHz is outside the caustic of the 430 MHz as well as the closest feed of carriage house 2 (1667 MHz). The impedance and radiation pattern of the 46.8-MHz feed was obtained by computer modeling, proving that the coupling with the nearby feeds is negligible to the impedance. However, influence to the radiation pattern could occur. The 5.3-m distance provides sufficient mechanical clearance to the surrounding guy wires.

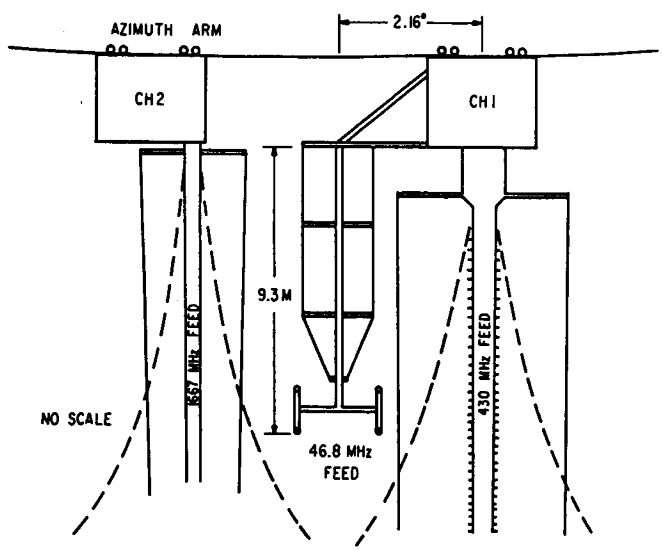

Figure 1. Schematic view (not to scale) of the carriage houses CH1 and CH2 with the 430-MHz, the new 46.8-MHz and the 1667-MHz feed. The dashed lines give the caustics of the two line feeds.

The height of 9.3 m below the paraxial surface was also obtained by computer modeling a point-feed above a spherical reflector. It was optimized to obtain maximum system gain for the chosen twin-Yagi feed antenna. The dimensions of the twin-feed antenna were designed to provide an elliptical illumination pattern of the spherical dish reflector (Figure 2a). The half-power beam width in the E-plane is 78° and in the H-plane, 62°. Since for pointing, the zenith angle is changed in the H-plane, spillover is minimized and the gain is kept almost constant out to maximum zenith angles of ≈ 17.81°. The selected illumination pattern and the height of 9.3 m below the paraxial surface corresponds to a (theoretically deduced) effective aperture of 43000 m^2, equivalent to 41-dB gain or 1.8° half power beam width. The effective aperture of 43000 m^2 is very close to the maximum aperture of 45000 m^2 which can be achieved with a 46.8-MHz point feed. The phase center of the twin feed is 2.16° downhill of the center of the 430-MHz line feed. This permits pointing the 46.8-MHz beam to zenith angles from −2.16° to + ≈ 17.84°, including the zenith direction. The twin feed was designed such that radiation in the horizontal direction would be minimized. The VSWR of the feed (with balun) is better than 1.22 within the band 45.8 MHz to 47.1 MHz. Since the return loss of the feed antenna is greater than 10 dB within the frequency range ± 5 MHz off the center frequency, it can also be used for offset frequency receiving (plasma line measurements for heating experiments). Although the absolute sensitivity of the 46.8-MHz antenna system could not yet be measured (because of interference problems and preferred radar operation), a drift scan indicated a beam width of 1.8° (see Figure 2b). The system sensitivity, estimated from the preliminary drift scan is expected to be larger than 10K/Jy. However, more correct pointing beam pattern and sensitivity calibrations have still to be performed to investigate pattern distortions due to coupling.

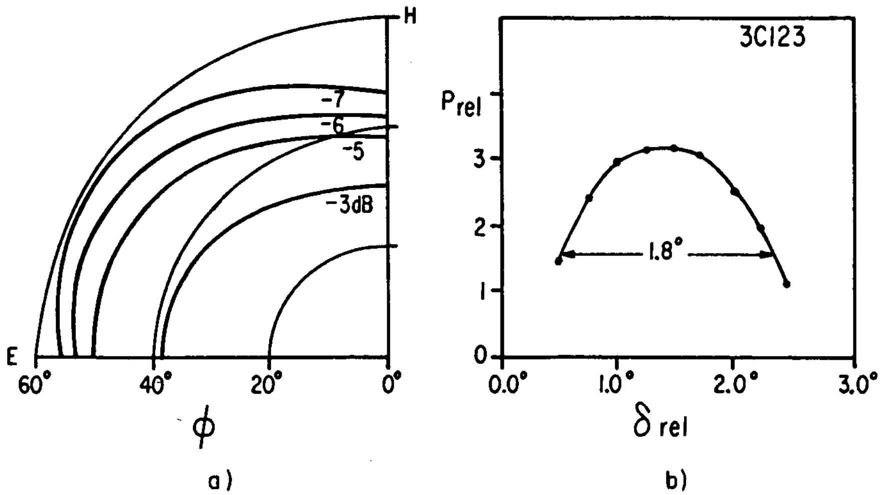

Figure 2. a) Illumination pattern of the spherical 1000 ft dish by the 46.8-MHz point feed. ϕ is the zenith angle, the 60° circles denotes the rim of the dish. H and E denote the H- and E-plane of the feed, which is moved in zenith angle in the H-plane. b) Relative power (P_{rel} = 3 corresponds to approximately 3000 k) measured by a drift scan through the radio source 3C123. This yields a preliminary half power beam width of 1.8° of the 46.8-MHz antenna system.

The method to determine the optimal parameters of the 46.8-MHz antenna system is described in more detail in this proceedings by IERKIC et al. (1986).

TRANSMITTER-RECEIVER

Figure 3 shows the setup of the transmitter/receiver unit which is located in carriage house 1. Essential additions to standard MST radar systems are the calibration noise injection into the receiver frontend, and the digital data link which allows to transmit the HV power supply and final amplifier status as well as the measured forward and reverse transmitter power values down to the control room. The nominal transmitter peak power is 50 kW at 2% duty cycle. The rise and fall times of the total transmitter system are 0.4 µs which allow proper use of pulses as short as 1 µs. The decoupling attenuation of the T/R switch (transmit-receive switch) and the pin diode SPST switch is 50 dB and their insertion loss is 2 dB. This will be improved by changing the pin diode switch which presently courses the main contribution of 1.8 dB to this loss. The noise figure of the receiver frontend is better than 0.5 dB on 46.8 MHz, it is increased by 0.5 dB at 4.30 MHz and 53.3 MHz. The calibration noise injection is presently set to 1690 K.

The received 46.8-MHz signal is amplified and sent to the control room via a 600-m long coaxial cable. All control and monitor signals are sent via other cables between the control room and carriage house.

RADAR CONTROL AND DATA PROCESSING

Figure 4 shows a block diagram of the instruments in the control and computer room. Two phase-coherent signals on 23.4 MHz and 70.2 MHz are used to

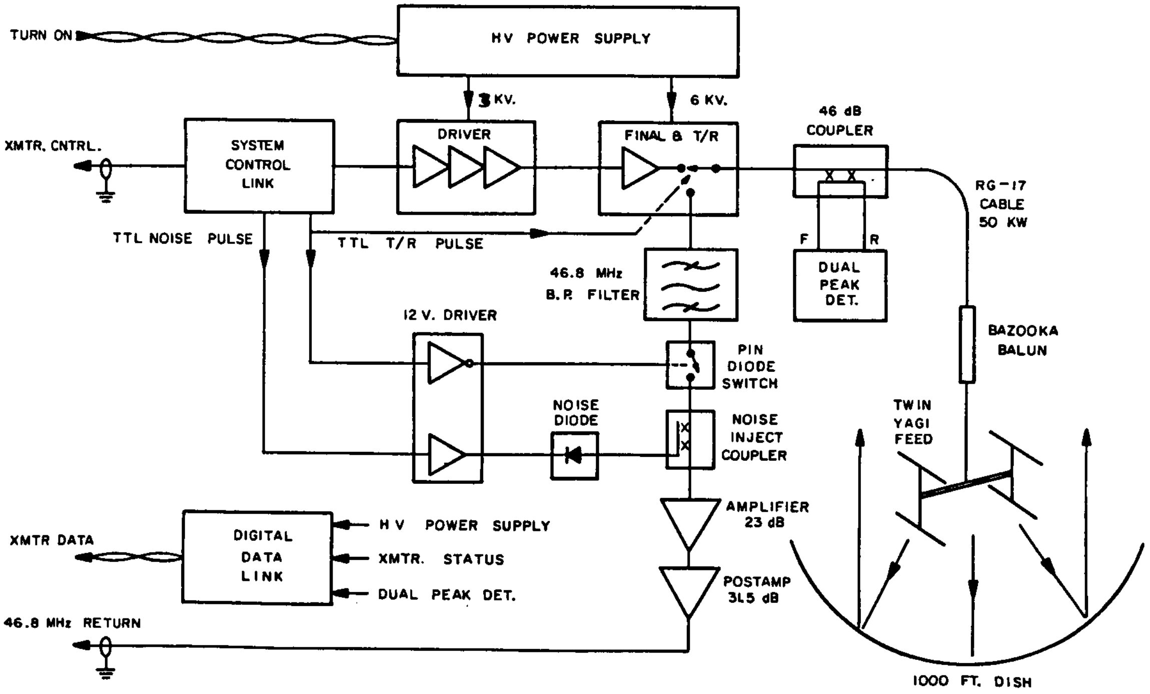

Figure 3. Instruments of the AO VHF radar located in the carriage house 1 on the platform.

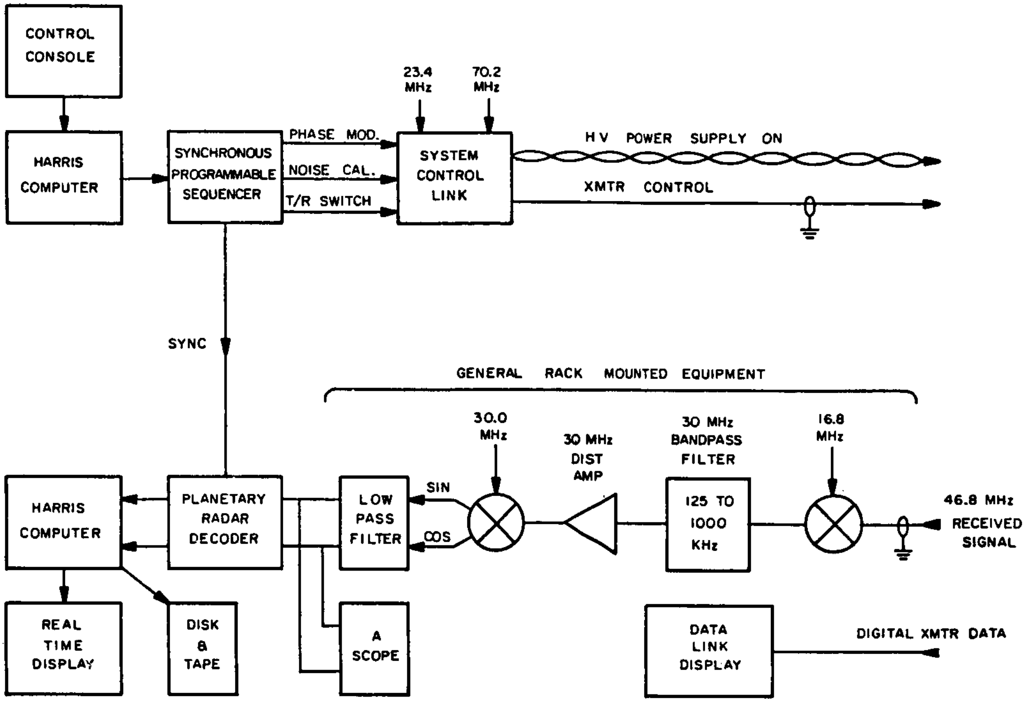

Figure 4. Instruments located in the control- and computer-room on the ground.

transmit the control signals (T/R switch, phase modulation, and receiver noise calibration) via a coaxial cable to the carriage house. These three control pulses are generated in the Synchronous Programmable Sequencer (radar controller), which is in turn controlled by the Harris 100 computer. Single pulse and any choices of complementary codes with interpulse phase flips (instrumental dc-elimination can be used). The RF pulse is derived from a combination of the noise calibration and T/R switch pulses. The pulses are checked in a hardware unit to see if limits of duty cycle (2% RF, 5% T/R) or pulse length (200 μs) are exceeded. The 70.2-MHz signal carries the noise calibration and the phase modulated RF pulse, and the 23.4-MHz signal carries the T/R pulse. These signals are mixed in the system control link (Figure 3) to yield the 46.8-MHz radar pulse.

The received 46.8-MHz signal is converted to the standard 30-MHz intermediate frequency and further to baseband. The planetary radar decoder is used for analog-to-digital conversion (10 bit), on-line decoding and coherent integration (max. 32 interpulse periods) of the quadrature signal. The output (a string of 16 bits selected from the 20-bit accumulator of the planetary decoder) of complex raw data for 2 x 256 range gates is fed to the Harris 100 computer, where it can be further coherently intergrated if desired. From the Harris 100 computer, the data are dumped on disk or tape (presently 1600 bpi, later to be changed to 6250 bpi). Also a real-time display of spectra, mean Doppler and power profiles will be provided.

Presently, only the raw data are dumped, since these are regarded more suitable than power spectra for system performance checks and some special

experiments. Power spectra could be computed on-line by using the array processor. This procedure would become necessary when also the 430-MHz radar will be used with the same radar control and acquisition software or for longer runs with the VHF radar to save tape.

FIRST RESULTS OF THE AO VHF RADAR

System definition and equipment development started in November 1984, (only the transmitter was purchased and further existing hardware was used), it was immediately followed by development of radar control and data-acquisition software utilizing the new Harris operating system, VOS, instead of the earlier DMS. Detailed tests of hardware and software took place in the second quarter of 1985, and first atmospheric echoes were recorded on tape on July 26, 1985.

Figure 5 shows a quick-look display (we acknowledge the software preparation done by D. N. Holden during his stay at the Observatory as a summer

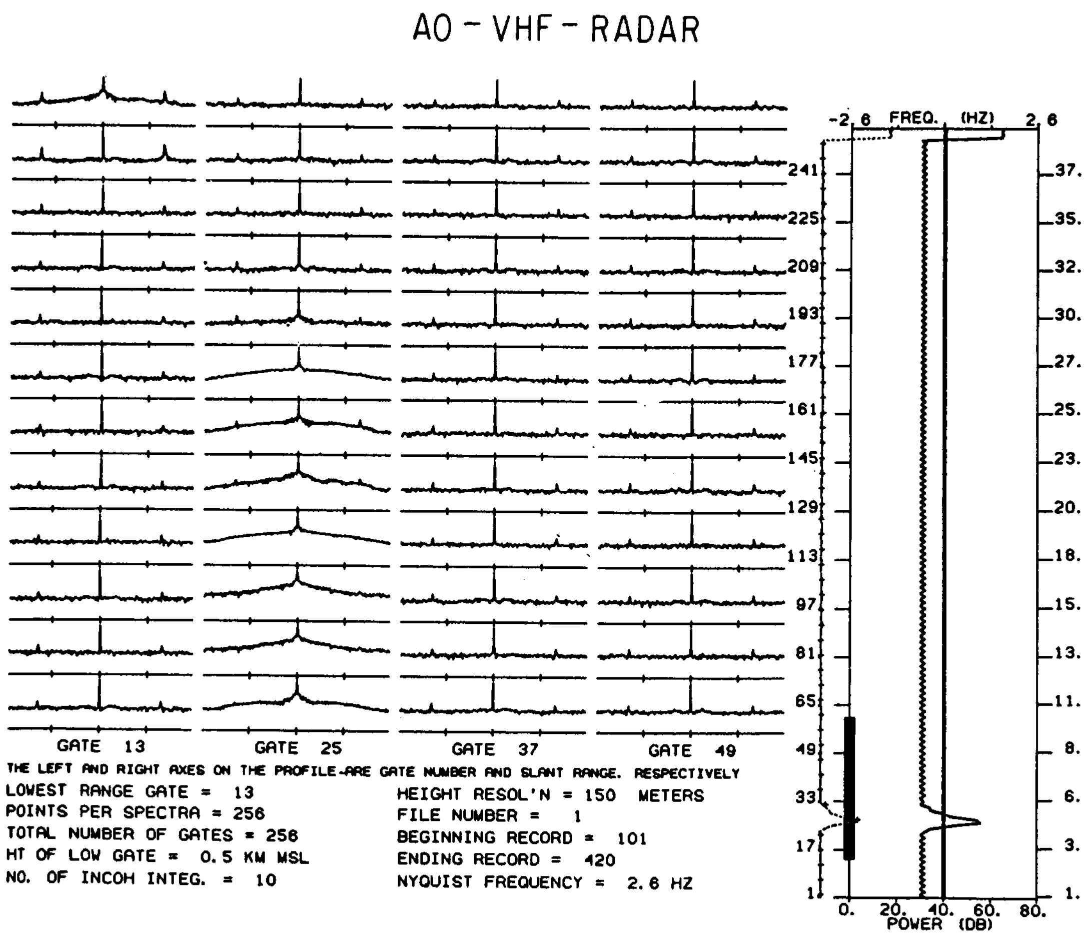

Figure 5. Sample of a real-time quick look plot of the AO VHF radar, displaying 48 normalized logarithmic spectra, and power profiles of dc - component, spectral peak, and noise as well as Doppler frequency of spectral peak. These spectra and profiles are showing results of a test run to check the system performance.

student), which is designed to monitor the data quality and later shall be attached to the system for real-time monitoring. It permits display of 48 normalized spectra of selected range gates and the total power profiles of the dc component, the spectral peak and the noise as well as the Doppler frequency of the highest spectral peak outside zero frequency. The display of Figure 5 presents results of a test series to measure the encoding/decoding properties and the spectral purity of the system. At gate 25, it shows the decoded (4 bit) transmitter pulse. These results prove the acceptable quality of the system, although improvements are desirable (e.g., suppression of code sidelobes). In particular, the graphs of Figure 5 indicate the sidebands of the transmitter pulse are more than 52 dB down at frequencies larger than 2.10^{-2} Hz. We regard this as an essential requirement because the system, due to the elevated feed antenna, intrinsically suffers from strong ground clutter. This would drastically hamper the data analysis if it were to spread out from zero Doppler shift.

Figure 6 shows a few sample spectra which indicate that the Doppler spread of the ground clutter on 46.8 MHz is apparently much less pronounced than that on 430 MHz (see SATO and WOODMAN (1980), who explained the spreading on 430 MHz due to fading by propagation effects). This evidence can be more directly seen in the profile of Figure 7, which proves that the difference between dc power and the (non-zero frequency) spectral peak is always larger than 40 dB. However, the absolute power of the ground clutter is severely large. Particularly in the lower ranges out to about 4-5 km, we will have some difficulties to avoid receiver saturation and to separate ground clutter from normal atmosphere echoes.

It also has to be mentioned here that the noise level frequently increases drastically due to interference in the radar band. We have partly identified the type of interference (spread-spectrum and narrow-band communication). It

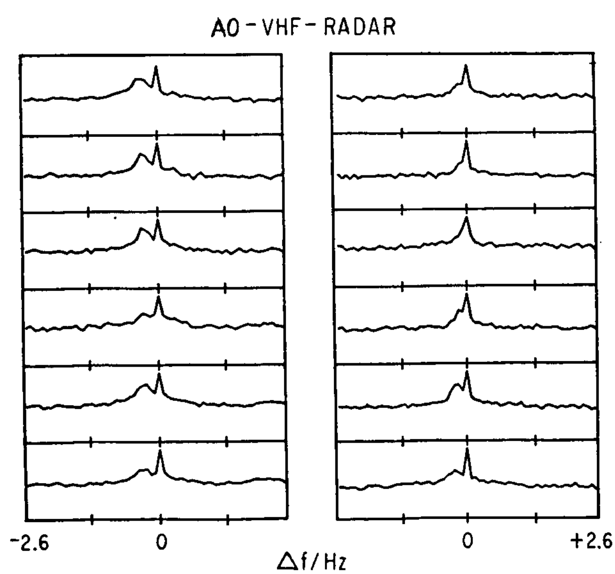

Figure 6. Selected spectra of tropospheric ranges obtained with vertical beam. Note that the power spectra are logarithmic and normalized to the maximum power in each range gate. The total power range changes between 60 dB and 90 dB.

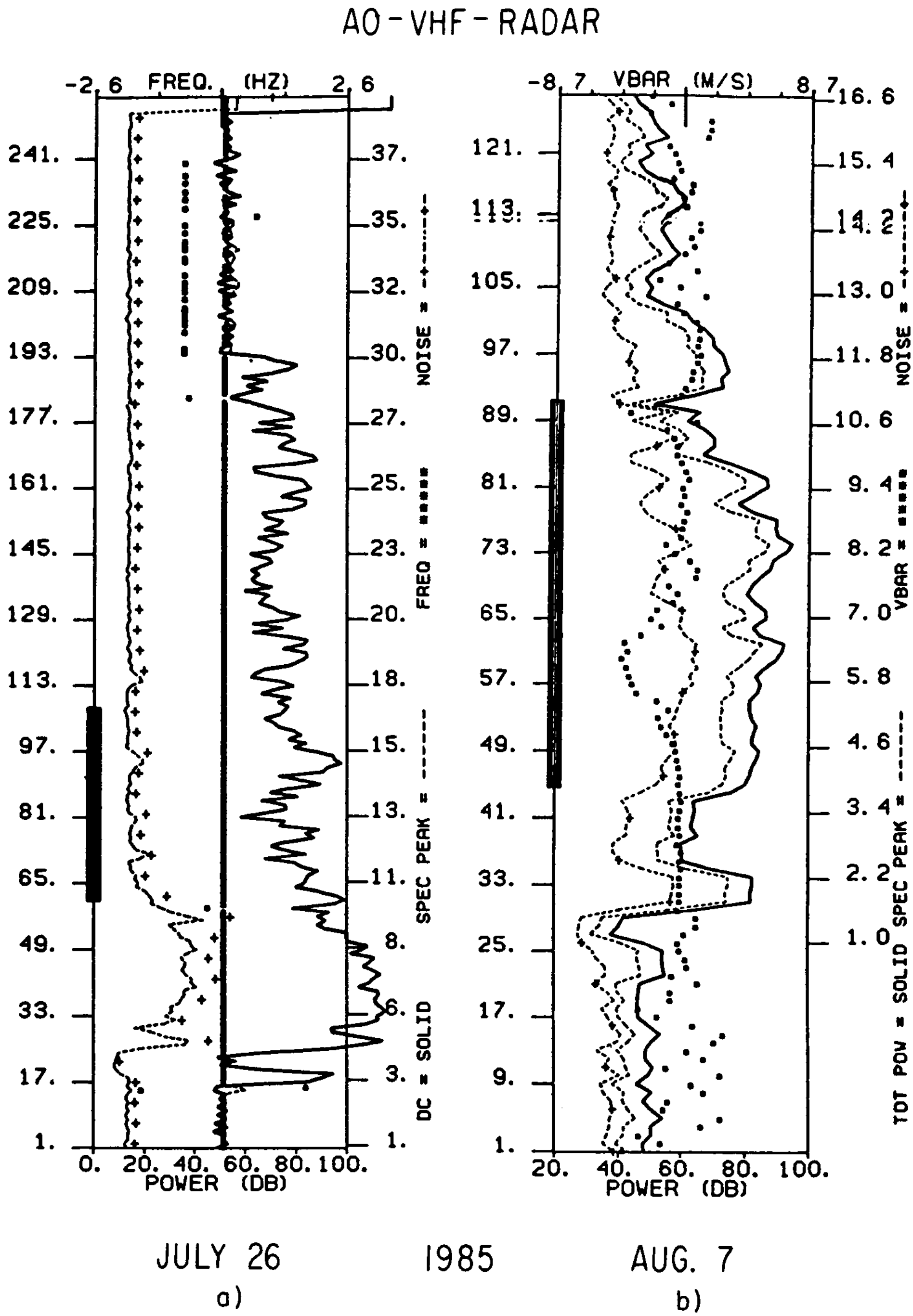

Figure 7. a) Quick look profiles of powers and Doppler frequency.
b) Profiles of power (total and peak of signal and noise power) and mean vertical velocity (VBAR) measured during the passage of a convective cloud. The right-hand side scale gives the altitude, whereas the left-hand scale gives range gate number.

appears impossible to eliminate this kind of interference with the presently used antenna setup. Only operation during noninterference hours or the use of a shielded phased array (at least for reception) would solve this problem. The latter solution was envisioned as phase 1 of the stand-alone VHF radar system which has been proposed to NSF.

Figure 7b shows profiles of more elaborate parameters, total power, spectral peak, mean velocity and noise, which were obtained (due courtesy of Larsen, Holden and Ulbrich) during the first application of the new VHF radar in experiments proposed by visiting scientists. The atmospheric echo power in this case was abnormally high because the echoes were from convective clouds. During this experiment HOLDEN et al. (1986) also used the 430-MHz radar with single pulse, and the results should be found elsewhere in this proceedings.

SUMMARY AND OUTLOOK

In addition to continuing use of the 430-MHz and 2380-MHz radars to study waves and turbulence with improved data taking programs and higher range resolution (on 430 MHz), we anticipate increased use of the 46.8-MHz radar. Besides improving this radar to make it more user-friendly, two further feeds are planned to allow fast beam steering, particularly to study in a better way gravity waves and turbulence and their interaction with the background wind.

Several experiments with the 46.8-MHz radar are presently being conducted have been proposed, or are scheduled: the measurement of momentum flux due to gravity waves (Woodman, Cornish, Ierkic, Rottger), measurements of wave number spectra of tropospheric stratospheric and mesospheric velocities (VanZandt, Rottger, Ierkic, Mathews, Ying), determination of the influence of the Doppler effect on frequency spectra of tropospheric, stratospheric, mesospheric velocities (Liu, Scheffler, Franke, Rottger, Ierkic, Mathews, Ying), range-Doppler study of shear instabilities in the MST region using fine-resolution techniques at Arecibo (Rastogi, Rottger, Ierkic), changes in cloud-droplet spectra associated with lightning (Larsen, Holden, Ulbrich), and further investigations of the scattering/reflection mechanism of 46.8-MHz radar echoes from the tropical troposphere and stratosphere (Rottger, Ierkic). It is foreseen, on the other hand, that strong attempts will continue to obtain funds for installing and operating a stand-alone 50-MHz radar facility for MST studies at the Arecibo Observatory.

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